

1 **Brief Communication: Future avenues for permafrost**
2 **science from the perspective of early career researchers**

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1 **Abstract**

2 Accelerating climate change and increased economic and environmental interests in
3 permafrost-affected regions have resulted in an acute need for more directed permafrost
4 research. In June 2014, 88 early career researchers convened to identify future priorities for
5 permafrost research. This multidisciplinary forum concluded that five research topics deserve
6 greatest attention: permafrost landscape dynamics; permafrost thermal modelling; integration
7 of traditional knowledge; spatial distribution of ground ice; and engineering issues. These
8 topics underline the need for integrated research across a spectrum of permafrost-related
9 domains and constitute a contribution to the Third International Conference on Arctic
10 Research Planning (ICARP III).

11

12 **1 Introduction**

13 Permafrost is a major component of the cryosphere, underlying 24% of the Northern
14 Hemisphere's land surface ([Zhang et al., 1999](#)). Due to rapid warming in the Arctic,
15 permafrost areas are now changing, with global implications for the carbon cycle and climate
16 feedback mechanisms ([Schaefer et al., 2012](#)). Despite the knowledge that permafrost areas
17 contain twice as much carbon (~ 1100–1500 Pg) as currently in the atmosphere ([Hugelius et
18 al., 2014](#)) and that permafrost temperatures have increased significantly during the last 20–30
19 years ([Romanovsky et al., 2010](#)), climate projections in the IPCC Fifth Assessment Report
20 (AR5) did not account for emissions from thawing permafrost, nor for the effects of
21 permafrost carbon feedback on global climate. Circumpolar permafrost areas in the Arctic
22 have been used for settlements and hunting grounds for indigenous peoples, resulting in a
23 legacy of knowledge. Conservation of cultural heritage sites and the construction of industrial
24 and municipal infrastructures on permafrost are costly and challenging.

25 Over the past two decades, the International Arctic Science Committee (IASC) and the
26 Scientific Committee on Antarctic Research (SCAR) have organized activities focused on
27 international and interdisciplinary perspectives for advancing Arctic and Antarctic research
28 cooperation and knowledge dissemination in many subject areas. For permafrost science,
29 however, no consensus document exists at the international level to identify future research
30 priorities, although the International Permafrost Association (IPA) highlighted the need for
31 such a document during the 24th IPA Council meeting in June 2012 ([IPA, 2012](#)).

1 This manuscript presents the outcome of an international and interdisciplinary effort
2 conducted by early career researchers (ECRs) in 2014. Online community input and a
3 conference workshop highlighted five priority research questions on the future avenues of
4 permafrost science. This consensus statement has been formulated in collaboration with the
5 IPA as a contribution to ICARP III from ECRs in order to raise permafrost issues to the
6 prominent position that they urgently deserve.

7

8

9 **2 Community consultation process**

10 Community input exercises are increasingly viewed as a valuable step towards
11 elaborating future research priorities or questions in a well-defined scientific community (e.g.
12 [Kennicutt et al., 2014](#); [Seddon et al., 2014](#)). We aimed to meet our goals of hosting an
13 effective large group dialogue by means of online question development followed by a World
14 Café conversational process ([Brown and Isaacs, 2001](#)). This process has been continually
15 evaluated following [Sutherland et al. \(2011\)](#). An overview of the process is provided in
16 Figure 1. This activity took place as part of an ECR Workshop held prior to the 4th European
17 Conference on Permafrost (EUCOP) in Évora, Portugal ([Schollaen et al., 2014](#)). Participants
18 were provided with live instructions (Supplement S3) including criteria what makes a
19 research question (cf. [Sutherland et al., 2011](#)).

20

21

22 **3 Breadth of questions**

23 Submitted questions covered a broad range of topics that focused on physical
24 processes (32), biogeochemistry (14), social interactions and impacts (9), engineering (9),
25 ecology (4), and modelling (3) (Supplement Table S1). Of the 20 questions that received
26 votes at the end of the World Café, 11 were associated with permafrost degradation or
27 changes in permafrost properties (Supplement Table S4). Tied for second were the keywords
28 “ground ice” and “carbon”, which are linked to two distinct fields in permafrost research.
29 Inter-related research topics such as “permafrost distribution”, “process-related” questions,
30 “hydrology” and “subsea permafrost” followed these three, and expressed less frequent but
31 nonetheless important research avenues.

1 **4 Highlighted research questions for permafrost science**

2 *4.1 How does permafrost degradation affect landscape dynamics at different spatial and* 3 *temporal scales? (Q1)*

4 Warming permafrost results in its degradation and in various interactions and
5 feedback processes (Romanovsky et al., 2010) operating at multiple spatio-temporal scales,
6 sometimes involving remarkable changes to landscape dynamics. While some of these regions
7 react slowly to long-term changes, others may respond abruptly to threshold crossing
8 (Rowland et al., 2010). Thermoerosion and mass movement can affect sediment and nutrient
9 fluxes. Melting of ground ice and the evolution of thaw lakes will affect hydrology and water
10 chemistry. These changes also interact with vegetation and snow cover, in a series of complex
11 feedbacks at the ground surface and in the active layer.

12 More accurate knowledge on the causes and consequences of permafrost degradation will
13 help to better assess community planning and landscape evolution models. Long-term
14 monitoring of currently degrading sites will facilitate identification and quantification of
15 tipping points and provide useful information on the development and recovery of the
16 landscape.. This will further enable the development of conceptual models that can help to
17 understand the timeframe, scale and frequency at which these processes operate.

18

19 *4.2 How can ground thermal models be improved to better reflect permafrost dynamics at* 20 *high spatial resolution? (Q2)*

21 In the rapidly warming Arctic, prediction of permafrost degradation is critical for
22 providing stakeholders with the tools they need to observe and plan for future effects on the
23 environment and human activities. From global to regional scales, a number of approaches
24 have facilitated mapping of the ground-thermal regime and its evolution over time in the past
25 years (e.g. Westermann et al., 2013). However, on the local scale, modelling tools are either
26 too simplistic or too complex to be used by others than modeling experts to provide answers
27 to many of the problems that Arctic communities will face in the near future. A main problem
28 is the availability of forcing data sets at such scales, which requires permafrost modeling in
29 conjunction with downscaling approaches (e.g. Zhang et al., 2012).

30 Future research should focus on identifying which processes are most important, so that
31 models with varying levels of complexity can be developed for Arctic stakeholders. Such

1 processes are for example controlled by the type and density of vegetation, snow cover, soil
2 moisture and human activity, which are in many cases interdependent (e.g. [Painter et al.,](#)
3 [2013](#)). Developing model representations for these processes is amongst the most urgent
4 challenges to improve projections on the fate of permafrost ecosystems and the carbon cycle.

5

6 *4.3 How can traditional environmental knowledge be integrated in permafrost research? (Q3)*

7 The circumpolar Arctic is inhabited by a variety of indigenous peoples. Having lived
8 in close contact with nature in the Arctic for a long time, they have observed changing
9 permafrost conditions that could provide valuable information to scientists. Traditional
10 Environmental Knowledge (TEK) incorporates practice and belief and evolves by adaptive
11 processes which are handed down through generations by cultural transmission. The highly
12 specialized knowledge about the Arctic environment is thus preserved in the collective
13 memory ([Henry et al., 2013](#) and references therein).

14 The description of environmental processes by the non-scientific community, including
15 indigenous peoples, often differs from that of the scientific community. This makes it
16 challenging to incorporate TEK into existing scientific methods. Although there are examples
17 of successful applications and integration of TEK for the purpose of co-management of
18 natural resources ([Tondou et al., 2014](#)), increased effort is still needed to evaluate the resilience
19 of Arctic communities ([Henry et al., 2013](#)). Successful adaptation to environmental changes
20 demands a holistic system perspective, to which permafrost science in the case of the Arctic
21 clearly can and should contribute.

22

23 *4.4 What is the spatial distribution of different ground-ice types and how susceptible is ice-* 24 *rich permafrost to future environmental change? (Q4)*

25 Ground ice is a fundamental component of permafrost soils. In the Arctic lowlands it
26 can occupy up to 80% of the soil volume in the upper 20-30 meters of permafrost. The
27 amount of ice and its vertical and lateral distribution are central parameters controlling the
28 thermal, physical and geochemical properties of permafrost deposits as well as their behavior
29 to thaw. Although many field studies characterize cryostructures, measure ground-ice content
30 and map ground-ice distribution, a concerted and organized mapping initiative that feeds into
31 international databases is still lacking. Until now, the National Snow and Ice Data Center has

1 been the principal database on ground-ice conditions, but it does not support the direct input
2 of field-based information by international researchers. Similarly, the Global Terrestrial
3 Network for Permafrost (GTN-P) is the primary international program concerned with
4 monitoring permafrost parameters (Biskaborn et al., 2015), but it does not include or provide
5 information on ground ice.

6 Efforts to address this issue should focus on remote sensing applications for landform
7 classification and on geophysical tools and drilling for the detection of subsurface ice.
8 Ground-ice-related information should be integrated in a dedicated database, such as GTN-P,
9 opening the door to regional extrapolation by integrating these data into climate models.

10

11 *4.5 What is the influence of infrastructures on the thermal regime and stability of permafrost*
12 *in different environmental settings? (Q5)*

13 Economic development in permafrost regions is facing numerous challenges since the
14 performance of engineering structures and transportation systems are reliant on the strength of
15 permanently frozen ground. Numerous examples exist where the combined effects of climate
16 change and inappropriate technical solutions have led to irreversible damages or have
17 required intensive maintenance and premature reconstruction (Bommer et al., 2010 and
18 references therein).

19 National guidelines and recommendations have recently been developed to adapt
20 infrastructures in permafrost areas (e.g. Bommer et al., 2010). Still, long-term evaluations of
21 these practices are needed to establish reliable tools and standardized guidelines. In order to
22 facilitate the evaluation of the construction and performance of the infrastructure in their
23 specific environmental context, future research needs to systematically integrate permafrost
24 engineering with earth sciences. A main challenge is to improve predictions of the behavior
25 and performance of structures and to act prior to unstable permafrost conditions develop. Test
26 sites in problematic permafrost areas are one way to address this challenge (Malenfant-
27 Lepage et al., 2012). Overall, integrating engineering knowledge with other fields of science
28 would benefit from and contribute to the impact assessments, socio-economic scenarios and
29 adaptation strategies (Vincent et al., 2013).

30

1 5 Synthesis

2 This collaborative, discussion-based consultation process allowed the community of
3 permafrost ECRs to work out the most urgent research questions to the future of permafrost
4 science. As such we would like to highlight research questions related to permafrost carbon
5 and its feedback dynamics as these are among the most popular topics in permafrost research
6 today (Hubberten et al., 2011). Questions Q1, Q2, and Q4 are all indirectly related to carbon
7 dynamics and Q9, Q13, Q14, and Q16 (Supplement Table S4) directly deal with this topic.
8 This demonstrates a specialization and fragmentation of our field as it grows rather than lack
9 of interest, and also a need for integration across disciplines (Vincent et al., 2013).

10 As the next generation of permafrost researchers, we see the need and the opportunity to
11 participate in framing the future research priorities. Across the polar sciences ECRs have built
12 powerful networks, such as the Association of Polar Early Career Scientists (APECS) and the
13 Permafrost Young Researchers Network (PYRN), which have enabled us to efficiently
14 consult with the community. Many participants of this community-input exercise will be
15 involved and also affected by the Arctic science priorities for the next decade within
16 permafrost research. Therefore, we need to i) contribute our insights into larger efforts of the
17 community such as the Permafrost Research Priorities initiative by the Climate and
18 Cryosphere (CliC) Project together with the IPA ([http://www.climate-](http://www.climate-cryosphere.org/activities/targeted/permafrost-research-priorities)
19 [cryosphere.org/activities/targeted/permafrost-research-priorities](http://www.climate-cryosphere.org/activities/targeted/permafrost-research-priorities)) and ii) help identify relevant
20 gaps and a suitable roadmap for the future of Arctic research. To critically evaluate the
21 progress made since ICARP II and to revisit the science plans and recommendations will be
22 crucial.

23 IASC and the IPA, together with SCAR on bipolar activities, should coordinate the research
24 agendas in a proactive manner engaging all partners, including funding agencies, policy
25 makers, and local populations. Communicating our main findings to society in a dialogue
26 between researchers and the public is a priority. Special attention must be given to indigenous
27 peoples living on permafrost, where knowledge exchange creates a mutual benefit for science
28 and local communities. The ICARP III process is an opportunity to better communicate the
29 global importance of permafrost to policy makers and the public.

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1 **The Supplement related to this article is available online at:**

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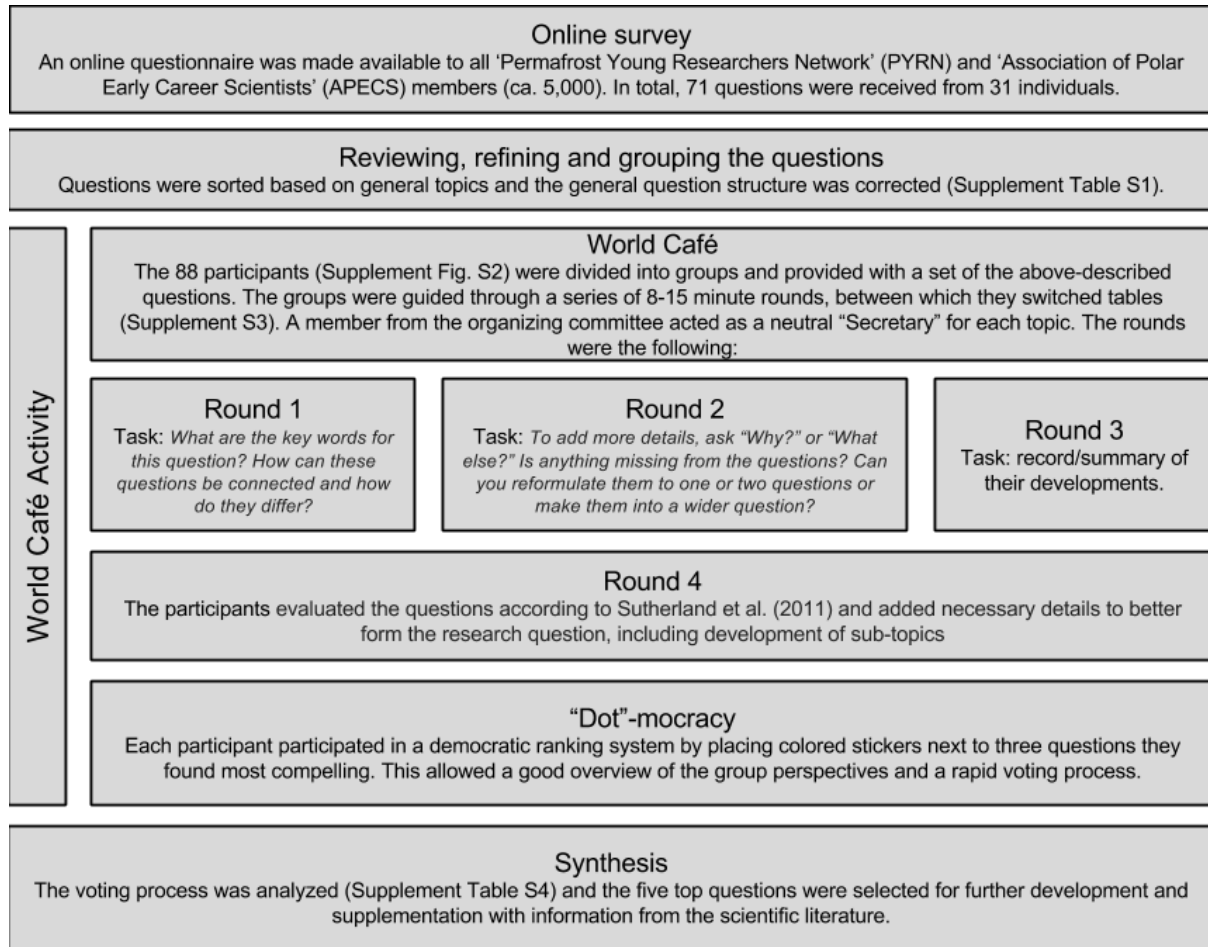
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1 Figures



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3 **Figure 1.** Flowchart of the process used to develop and refine future research questions.
4 Questions were initially developed via an online survey. After some refinement, the process
5 continued with an on-site World Café (Brown and Isaacs, 2001) workshop. Questions asked
6 throughout the World Café enabled participants via group discussion to consider structure,
7 breadth and depth of the questions (Sutherland et al., 2011). Workshop participants
8 (Supplement Fig. S2) voted to identify the questions they believed to be the most compelling
9 as a final step in the on-site activities. Based on votes, five questions were selected for further
10 development and dissemination. The collaborative nature of the activities, coupled with
11 substantial interest from all participating ECRs, enabled high levels of participation and
12 thoughtful discussions about the future of permafrost research. Detailed workshop guidelines
13 are given in Supplement S3.